PROPERTIES OF THE "GUGLER PRIMARY BATTERY"

BY

A. A. PERRINE

ARMOUR INSTITUTE OF TECHNOLOGY

1912

AN EXRERIMENTAL DETERMINATION OF THE PROPERTIES OF THE "GUGLER PRIMARY BATTERY"

A THESIS

PRESENTED BY

ARTHUR A.R.PERRINE

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE

OF

ELECTRICAL ENGINEER.

MAY 1912.

Approved

E. H. Freeman

Prof. of Elect. Eng.

H M Raymond

TABLE OF CONTENTS.

BIBLIOGRAPHY.

"Electricity and Magnetism", by
[illegible]
"Electrical and Magnetic [illegible]",
[illegible]
The "Voltaic Cell" by [illegible]
"Galvanic Batteries", by [illegible]
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by Carl Hering. [illegible]

CALIBRATION OF INSTRUMENTS.

Calibration of Instruments.

The instruments used to measure the current and voltage for these tests were Weston Volt-meter Model 45 #6093 and Weston Milli-volt meter Model 45 #5792 with one and ten ampere shunts.

It was deemed advisable to calibrate the instruments used by comparing them with a standard instrument known to be correct on account of the tendency of electrical instruments to read incorrectly after a time by reason of their construction or due to mechanical injury.

Each instrument was calibrated both before and after the test and an average value taken from the calibration curves in place of the observed readings. These average values were used in plotting curves and making calculations. The original data as read directly from the instrument was not recorded.

The calibration curves using the average values follow.

[illegible] Volt[illegible]

Test [illegible]
V[illegible]ter ([illegible]) #5050. [illegible]

.1	[illegible]
.2[illegible]	.[illegible]
.3[illegible]15	.[illegible]
.43	[illegible]
.[illegible]	.[illegible]
.[illegible]	[illegible]
.[illegible]	[illegible]
.[illegible]25	[illegible]
.[illegible]	.[illegible]
.[illegible]	.[illegible]
1.[illegible]	1.[illegible]
1.1[illegible]	.[illegible]
1.[illegible]	.[illegible]
1.[illegible]	1.[illegible]
1.[illegible]	1.[illegible]
1.[illegible]	[illegible].[illegible]
1.[illegible]	.[illegible]
.[illegible]	.[illegible]
.[illegible]	.[illegible]
.[illegible]	.[illegible]
.[illegible]	.[illegible]
.[illegible]	.[illegible]

[illegible]

[illegible] of [illegible] [illegible]

[illegible] [illegible] papers [illegible]

Laboratory [illegible]
[illegible] meter [illegible]
[illegible]

.1	.1
.2	[illegible]
.3	[illegible]
.4	[illegible]
.5	[illegible]
.6	[illegible]
.7	[illegible]
.8	[illegible]
.9	.9[illegible]
.[illegible]6	1.[illegible]

Temperature [illegible]

Calibration [illegible] Weston [illegible]

[illegible] 1 [illegible] res [illegible].

Laboratory Standard [illegible] [illegible]
Weston [illegible] 7442 and 15 [illegible]
shunt [illegible].

1. [illegible]

2. [illegible]

3. [illegible]

4. [illegible]

5. [illegible]

6. [illegible]

7. [illegible]

8. [illegible]

9. [illegible]

10. [illegible]

Temperature of [illegible].

Primary electric [illegible]

[illegible]

[illegible]

its [illegible]

[illegible] electricity [illegible]

[illegible]

[illegible] the [illegible]

its [illegible]

neglected.

The [illegible]

[illegible]

so many batteries [illegible]

[illegible]

[illegible]

to observe the [illegible]

material [illegible]

[illegible]

[illegible]

teries. [illegible]

[illegible]

[illegible]

[illegible] process [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

dynamo. This great advantage is more than counter-balanced by the fact that the fuel consumed in the primary batteries is much more expensive than that used in steam engines. Yet while this fact is true for the production of large quantities of electrical energy, it is also true that for the production of smaller quantities of electrical energy the primary battery has quite an advantage in regard to economy of cost over the installation of an engine and dynamo plant.

It is the primary purpose of this investigation to bring out the more important points in the behavior of the Lupien primary battery. To this end four cells were tested, three potassium chlorate cells and one blue stone cell. In order to have the conditions of the test as near as possible to those under which the batteries are operated in practice: the electrolyte was prepared with ordinary tap water and the cells were placed in a room in which the temperature would be about [illegible] F. [illegible] the average temperature was a little low, it was as good as could be secured without artificial heat and this was not deemed expedient.

The cells submitted for the test were of temporary construction, [illegible] changes in design of [illegible] the

cells will be placed [illegible] [illegible]. [illegible] details and consist merely of a [illegible] [illegible] [illegible]lar grooved [illegible] to [illegible] [illegible] and a suitable cell cover.

The Tyler cell has not been [illegible] [illegible] service although cells of this type have been [illegible] [illegible]tinuous discharge at the Western Union Telegraph [illegible], for more than twenty months on [illegible] charge. The [illegible] shows possibilities [illegible] [illegible] "Blue Stone" and "[illegible] [illegible]" [illegible] [illegible] used on signal service.

Before assembling the cells [illegible] [illegible] [illegible] was carefully weighed and recorded. The weight [illegible] each cell will be found under "[illegible] of [illegible] [illegible] [illegible] of Cells". After assembling the cell [illegible] cell was labeled [illegible] [illegible] [illegible] No. 1, No. 2, No. 3, [illegible] No. 4. [illegible] [illegible] [illegible] of Mr. Tyler cell No. 1 was discharged through constant [illegible] [illegible] [illegible] approximately [illegible]-five amperes by adjusting resistance [illegible] [illegible] after cell had been in operation [illegible] [illegible]. [illegible] Nos. 2 and 3 were discharged through [illegible] [illegible] resistance on separate circuits [illegible] every [illegible] [illegible] for a period of ten seconds [illegible] [illegible] approximately 2.5 amperes [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

a [illegible]. Cell No. 4 was the [illegible] sulphate or gravity cell. This cell [illegible] tested to secure comparative data. The discharge being through a permanent resistance [illegible] current rate of approximately .5 amperes at the start. Each test will be explained in detail with the accompanying data and curves independently of the other tests.

HISTORY OF THE PRIMARY BATTERY.

In the year 1767 Sulzer p[illegible] which was read before the Academy [illegible] Berlin, in which he announced [illegible] when two pieces of metal, one of [illegible] of silver are placed together [illegible] such a manner that their edges are [illegible] peculiar taste is perceived. The importance of Sulzer's observation was not appreciated until Galvani had made his important discovery [illegible]ly prepared frogs' legs when suspended by copper wire above an iron railing, twitched [illegible] whenever a portion of the leg touched the iron; [illegible] Volta had demonstrated that this phenomenon [illegible] due to the presence of animal tissue but [illegible] the metals themselves, giving rise to Volta's contact theory of electrical excitation which [illegible] that is now known as the "difference of potential" exhibited by two metals due to a simple contact and not depending upon the medium in which they are immersed.

During the same year that Galvani's [illegible] work appeared, Galvani described experiments which he had made with metals that he had plunged into water and said he was satisfied that a chemical action had taken place and that it was the slow combustion [illegible]

oxidation of the metal which gave rise [illegible] stimulus.

The fact that the difference [illegible], resulting from a single pair of metals lying in [illegible] an aqueous liquid, can be thus multiplied by arrang- ing in order a number of such pairs connected together, was discovered by Volta in 18[illegible]. [illegible] the effect in a marked degree, he arranged a number of alternate layers of zinc and copper; each pair of metals being separated from the next by [illegible] with acidulated water. The [illegible] Volta called his "electro-motive [illegible]", but is more familiarly known as Volta's Pile.

A pile of this kind when composed of [illegible] or more of these pairs of plates produces an [illegible] physiological effect when the terminals of the pile are placed upon the tongue.

This pile lead to the development of Volta's "crown of cups" which was the first real voltaic bat- tery or device which would produce a continuous flow of electricity. This device consisted of a series of glasses or cups placed in a circle; plates of copper and zinc were connected and arranged so that a plate of zinc was placed in one cup and a plate of copper in the next.

The oldest battery of commercial importance, which does not have a depolarizer is the Smee, developed in 1840. This cell has a positive plate of zinc and a negative plate of thin silver, corrugated and covered with platinum. The purpose of the roughened surface was to facilitate the release of the hydrogen which is released at this plate. The exciting liquid used in this cell was sulphuric acid.

Amalgamation of the zinc was introduced by Sturgeon in 1830. The two-fluid type of primary cell with porous cup to separate the fluids was invented by Daniell in 1836. Grove, in the same year, introduced the use of nitric acid as an electro-negative fluid more powerful than the copper sulphate of Daniell's cell. Grove used a platinum negative plate to withstand the action of the nitric acid, and in 1842 Bunsen substituted carbon for this expensive metal. Poggendorff in the same year devised a single-fluid cell in which a solution of potassium bichromate mixed with sulphuric acid was used as a depolarizer instead of the nitric acid of Grove, thereby avoiding the obnoxious fumes of [illegible] material [illegible].

Most of the batteries which have been developed since the Daniell cell are modifications [illegible].

form, either of its elements, it [illegible] the depolarizer used.

In the primary battery designed and constructed by Mr. G[illegible]gler during the past year, a cylindrical electrode of carbon is used for the positive element surrounded by annular carbon filling most of the space in the jar outside of the carbon [illegible] cylindrical sheet of zinc placed in the porous cup. Two rounds of [illegible] used [illegible] make contact with the negative electrode. The electrolyte used for both the outer and inner solutions was sulphuric acid.. Potassium chlorate was added to the outer solution for the depolarizer.

THEORY OF THE VOLTAIC [illegible].

When commercial zinc is [illegible] dilute sulphuric acid it is dissolved [illegible] and liberating hydrogen. During [illegible] zinc is being dissolved considerable energy is liberated in the form of heat.

If chemically pure zinc is dipped into dilute sulphuric acid very little action takes place and the small quantity of liberated hydrogen [illegible] attached to the zinc plate protecting it [illegible] action of the acid.

If [illegible] plates of [illegible] the [illegible] touching, no apparent action ensues, but if wires of copper or other material are attached to each plate, they are found to differ in potential. If the wires are connected to the terminals of a sensitive electrometer [illegible] deflection is produced indicating a difference of potential of approximately one volt, the potential [illegible] to the copper [illegible] being the greater.

Results similar to the above [illegible] be obtained if almost any two metals are used in place of the copper and zinc in the above experiment, [illegible] water which contains a small quantity of a salt in solution. The only difference in the results [illegible] be in the magnitude of the potential observed.

If now the wires are connected [illegible] action ensues, the zinc [illegible] hydrogen is [illegible] rapidly liberated from the [illegible] plate.

Clausius advanced [illegible] theory of the action within the electrolyte [illegible] that the ions of any molecule are not [illegible] to one another but that a continual interchange of partners, as it were, takes place between the [illegible] of different molecules. Thus, in a solution of sodium chloride, the sodium and chlorine of any molecule do not long remain attached to each other, the sodium changes places with the sodium of [illegible] molecule and the chlorine [illegible] with the free chlorine of a third molecule. This interchange is continually going on at random as long as no outside directive force is applied. [illegible] in the free state, between moves [illegible] carries a positive or negative charge of electricity.

If we assume with Helmholtz that [illegible] (electrode) has a specific attraction for [illegible], and therefore for the ionic charges, it [illegible] be assumed that zinc attracts a positive charge less forcibly and a negative charge more readily than copper does. Consequently, when plates of copper and zinc are immersed in sulphuric acid, there is an attraction of the negative ion towards the zinc.

As this interchange of ions [illegible] be drawn to one or the other [illegible] plates, where they will be [illegible], [illegible] respective charges of electricity. [illegible] tinues until it is arrested [illegible] respective charges accumulated [illegible] infinitesimal chemical action [illegible] electrical connection is made [illegible] copper plates. Negative electricity then flows toward the copper plate and unites with the positive charge of the hydrogen atoms which moves toward the copper plate to meet the negative current. The [illegible] hydrogen gas is liberated at the copper plate. [illegible] stream of hydrogen [illegible] same direction, probably by successive molecular interchanges and deliver their charges of electricity to the copper plate. This action [illegible] after the external circuit is broken [illegible] separated electrical charges [illegible] check the [illegible] repulsion of like charges, [illegible] ceases. [illegible] is the condition of open circuit. [illegible] will then be [illegible] exhibit a difference of potential.

The chemical action [illegible] cell on open circuit, [illegible] able potential energy. [illegible] local action which does not [illegible] production of useful current. [illegible] This action is always present [illegible] is used, and is due to impurities [illegible] nature; as soon as these [illegible] are [illegible] the electrolyte, a local [illegible] zinc, causing the zinc to [illegible] site.

To prevent this wasteful [illegible], the zinc is amalgamated with mercury. [illegible] accomplished by dipping [illegible] sulphuric acid [illegible] with mercury.

This amalgam [illegible] zinc leaving [illegible]. The impurities are gradually [illegible] cell, thereby preventing the wasteful [illegible] local currents. This amalgam of zinc with [illegible] does not entirely prevent local action but [illegible] duces it [illegible] small value as compared [illegible] value the local action [illegible] if [illegible] not used.

POLARIZATION AND DEPOLARIZATION.

When a simple element, consisting of plates of zinc and copper in diluted sulphuric acid, is allowed to generate a current, [illegible] at the copper plate. A small amount of this hydrogen adheres to the surface of the plate giving rise to an electromotive force which opposes that of the cell. Consequently, the E. M. F. of the cell diminishes as soon as a current is generated. This decrease of potential of the cell increases with an increase of current flowing. In addition to a reduction of the E. M. F. of the cell due to the decomposition of the electrolyte, the formation of hydrogen is also objectionable in that it forms in a layer on the surface of the cathode, thereby greatly increasing the internal resistance of the cell. This formation of hydrogen upon the surface of the cathode is called polarization.

The removal of this free hydrogen from the surface of the cathode by any means is called depolarization, and the removing agent, the depolarizer. It may be removed mechanically by agitating the electrolyte or by temporarily removing the cathode from the electrolyte when the cell is not in use. The chemical method is the most common method of depolarization used, and consists in placing some substance at or near the surface of the cathode with which the free hydrogen may unite, [illegible]

[illegible]

[illegible]

Batteries [illegible]

batteries [illegible]

[illegible]

[illegible]

[illegible]

[illegible] resistance [illegible]

[illegible]

[illegible] 13

differentiated [illegible]

[illegible] current [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

$$[illegible]$$

$$[illegible]$$

This [illegible]

[illegible]

[illegible] H_2SO_4 [illegible]

chlorine [illegible]

[illegible]

DESCRIPTION OF THE CELL.

The cells tested were made by [illegible] Company of [illegible], [illegible] "[illegible] Primary Battery"

The cells were all of one type and consisted in brief of an outer containing jar [illegible] holding the electrolyte, depolarizer, zinc cylinder, granular carbon, surrounding the inner porous cup. This porous cup contains the [illegible] element with its terminal; contact being made between the terminal and zinc by means of a screw. The cup is filled to one-half inch of the top with the same electrolyte as was used in the outer containing jar.

The different parts entering into each completed cell were as near a duplicate of each other as they could be commercially made. The weights of the parts entering into the construction of the cells are tabulated for each cell under "Weights of Parts Composing Cells"

The glass containing jar was [illegible] inches in diameter and 11.[illegible] inches high and made of glass approximately .11 of an inch thick. The bottom of the jar at one point is formed into a [illegible] so that all the electrolyte will drain down into the [illegible]

little pocket as the cell is drained. The total capacity of the glass is 5[illegible]5.54 cubic inches and the volume of a vertical section of the jar one inch in height is 5[illegible].7 cubic inches.

The large carbon cylinder used was [illegible].75 inches high and had a diameter of [illegible].95 inches. The thickness of the material forming it was .[illegible]75 inches. A small cylindrical projection from the top of carbon of a diameter of approximately 1.5 inches with a reduced diameter at its top forming a shoulder forms a contact lug. In this reduced portion a metal cap is cast of an expanding alloy which firmly binds the carbon in cooling. Over the metal cap a glass cap is placed which rests on the shoulder of the carbon lug and is made tight with a compound between the glass and carbon joint. The glass cap is larger internally than the metal cap and this space is filled with a mineral oil which effectually prevents [illegible] electrolysis between the carbon and metal couple. The glass cap has an axial perforation with a raised boss. On top of this cap another glass cap is placed in an inverted position forming a cup. Through this glass cup and cap a sleeve connector with a threaded stud on one end is passed and is drawn down tight by screwing in a threaded hole in the metal cap. The

abutting [illegible]

[illegible] is required to [illegible]

inverted cup [illegible]

is filled with oil [illegible]

carbon electrode [illegible]

against corrosion.

After inserting [illegible]

[illegible] long [illegible]

bottom of the [illegible]

between the surface of the [illegible]

trode is filled with [illegible]

site from the [illegible]

ing a mesh [illegible]

[illegible]

[illegible]

The [illegible]

.180 inches [illegible]

12.75 [illegible]

[illegible]

electrode [illegible]

into the [illegible]

[illegible] 12 [illegible]

[illegible]

terminal [illegible]

[illegible] sted.

The zinc [illegible] a cylinder [illegible] inches [illegible] 3.5 inches and formed [illegible] by rolling from a flat pl[illegible] approximately one half inch [illegible] of [illegible] cylinder.

The cell is set [illegible]. After washing the glass jar, [illegible] to remove dirt or other impurities, [illegible] der is placed in the glass containing jar. The [illegible] tube for draining off the [illegible] ter solution is inserted in the pocket of the glass jar, then the remaining space between the carbon cylinder and the glass jar is filled with granular carbon which [illegible] size of .27 inches, [illegible] 7 inches is [illegible], then [illegible] carbon having [illegible]. One pound of [illegible] of the granular carbon.

The porous cup [illegible] n- side of the carbon cylinder, and [illegible] - ry was poured into it. The [illegible] terminal [illegible] placed in the cup.

In order [illegible] near as possible [illegible] practice

ordinary [illegible] used [illegible] electro-lyte. To a [illegible] chemically pure [illegible] gravity of 1.8[illegible] 1.115 specific gravity at a temperature of [illegible] Fahrenheit is secured. A portion of this electro-lyte is then poured [illegible] .5 inches from the top [illegible] solution is determined by subtracting [illegible] the containing jar from the original [illegible]. Ad-ditional electrolyte is then [illegible] around the carbon [illegible] until [illegible] inches from the top of the edge [illegible]. The weight of this outer [illegible] be-fore. The weight of the electrolyte [illegible] each cell was thus determined.

The cell [illegible] for ten hours before [illegible] allow the [illegible]. The [illegible] the cell on [illegible] Fahrenheit or [illegible] volts. The voltage [illegible] cells immediately after assembling was .1[illegible] the value [illegible] .[illegible]9 to 1.[illegible] volts.

[illegible]

The reason that the voltage did not reach [illegible] value was probably partly due to the fact that the temperature was rather low.

The cell may be recharged by syphoning the old solution off and adding a new solution having a gravity two degrees higher than the original solution in order to compensate for the water left in the receptacle from the previous solution. The syphoning apparatus consists of two lengths of rubber tubing connected by a rubber bulb, one of the free ends of the apparatus is to be placed in the liquid to be syphoned and the other end in the receptacle into which the liquid is to be transfered. The receptacle being below the top of the electrolyte the flow can be started by compressing the bulb, closing the opening below the bulb and allowing the bulb to expand, and the liquid to be forced over into the bulb. [illegible] released the electrolyte will continue to flow until all the liquid is transferred or air enters the [illegible] end of the tube destroying the vacuum.

WEIGHTS OF MATERIALS.

Weights of Component Parts of Cell Number One.

Glass jar,	6.798	Lbs.
Zinc,	4.05875	"
Porous cup,#53S,	1.773	"
Carbon terminal,	6.383	"
Gass syphoning tube,	.0743	"
Grannular carbon,	3.582	"
Mercury.	2.	"
Potassium chlorate,	1.	"
Contact rod to zinc terminal	.219	"
Outer solution,	6.355	"
Solution in porous cup,	3.847	"
Total weight,	36.09005	"
Weight of zinc plus mercury after test,	5.688	"

Weights of Component Parts of Cell Number One.

Glass jar,	6.798	Lbs.
Zinc,	4.05375	"
Porous cup. #532,	1.773	"
Carbon terminal,	6.383	"
Gass syphoning tube,	.0743	"
Granular carbon,	3.582	"
Mercury.	2.	"
Potassium chlorate,	.1	"
Contact rod to zinc terminal	.219	"
Outer solution,	6.356	"
Solution in porous cup,	3.847	"
Total weight,	36.09005	"

Weight of zinc plus mercury after test, 5.983 "

Weights of Component Parts of Cell Number Two.

Glass jar,	6.907	Lbs.
Zinc,	4.0625	"
Porous cup,	1.626	"
Carbon terminal,	6.477	"
Glass syphoning tube,	.0743	"
Grannular carbon,	4.1543	"
Mercury,	2.	"
Potassium chlorate,	1.	"
Contact rod to zinc terminal,	.219	"
Outer solution,	7.237	"
Solution in porous cup,	3.106	"
Total weight,	36.8631	"

Weight of zinc plus mercury after test,	5.663	"

Weights of Component Parts of Cell Number Two.

Glass jar,	6.607 lbs.
Zinc,	.0625 "
Porous cup,	1.626 "
Carbon terminal,	6.477 "
Glass syphoning tube,	.0742 "
Granular carbon,	4.1545 "
Mercury,	.2 "
Potassium chlorate,	.1 "
Contact rod to zinc terminal,	.219 "
Outer solution,	7.237 "
Solution in porous cup,	2.106 "
Total weight,	36.8631 "

Weight of zinc plus mercury after test, 5.663 "

Weights of Component Parts of Cell Number Three.

Glass jar,	6.682	Lbs.
Zinc,	4.0625	"
Porous cup. S50,	1.860	"
Carbon terminal,	6.688	"
Glass syphoning tube,	.0743	"
Grannular carbon,	3.893	"
Mercury,	2.	"
Potassium chlorate,	1.	"
Contact rod to zinc terminal,	.219	"
Outer solution,	6.739	"
Solution in porous cup,	3.536	"
Total weight,	36.6538	"
Weight of zinc plus mercury after test,	5.663	"

Weights of Component Parts of Cell Number Four.

Glass jar,	3.356	Lbs.
Zinc terminal,	3.992	"
Copper terminal,	.1211	"
Copper sulphate,	1.5	"
Weight of water,	7.265	"
Total weight,	16.2341	"
Weight of zinc after test	2.52	"

P A R T I.

T E S T NO. I.

DISCHARGING AT A CONSTANT RATE.

F I G U R E I.

A SCHEME OF THE CONNECTIONS USED IN MAKING THE TESTS.

T E S T NO. I.

The apparatus used in performing the tests, other than the batteries, consisted of the following:

(1) 0-3 Direct current, direct reading Weston volt meter.

(2) 0-100 Milli-volt meter and ampere shunts for 1 and 10 amperes.

(3) Coil resistances and wire.

(4) 3 Double pole, double throw switches.

(5) 3 Single pole, single throw switches.

(6) 1 Three pole double throw switch.

(7) 6 Volt storage battery.

(8) Clock with second-hand attachment.

(9) 2 Auxiliary relay coils.

(10) 1 Contact counter.

TEST NO. 1.

The apparatus used in performing the tests, other than the batteries, consisted of the following:

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(7) 6 Volt storage battery.

(8) Clock with second-hand attachment.

(9) 2 Auxiliary relay coils.

(10) 1 Contact counter.

The apparatus was connected according to the scheme shown in Figure 1. Battery #1 was connected in series with switch #2, and resistance r_1, now by throwing switch #7 to the left, the closed circuit voltage may be read on voltmeter V, and by opening switch # 2 the open circuit voltage may be read. The current of cell # 1 was determined by throwing switch # 5 to the left and opening switch # 2.

Cell # 2 was connected with a counting relay, auxiliary relay contact, switch # 1, and resistance r_2 in series. By throwing switch # 4 to the left and opening switch # 1, the current may be read on ammeter A_2. The voltage can be read by throwing switch # 6 to the left.

Cell # 3 was connected through a switch # 7, resistance r_3 and an auxiliary relay.(contact) The current was determined by throwing switch # 4 to the right and opening switch # 3. The voltage being read by throwing switch # 6 to the right.

Readings of battery # 4 were determined by inserting the ammeter shunt A_1 in the circuit, and connecting the Voltmeter across the terminals.

On the data sheets "I" is the current in amperes: E_1 is the closed circuit voltage: E_2 is the open circuit voltage: D is the density in degrees Baume: and "r" is the resistance of the cell.

The apparatus was connected according to the scheme shown in Figure 1. Battery #1 was connected in series with switch #2, and resistance r, now by throwing switch #7 to the left, the closed circuit voltage may be read on voltmeter V, and by opening switch # 2 the open circuit voltage may be read. The current of cell # 1 was determined by throwing switch # 5 to the left and opening switch # 2.

Cell # 2 was connected with a counting relay, auxilliary relay contact, switch # 1, and resistance r_c in series. By throwing switch # 4 to the left and opening switch # 1, the current may be read on ammeter A_2. The voltage can be read by throwing switch # 3 to the left.

Cell # 3 was connected through a switch # 7, resistance r_L and an auxilliary relay contact. The current was determined by throwing switch # 4 to the right and opening switch # 7. The voltage was read by throwing switch # 6 to the right.

Readings of cell by # 4 were determined by inserting the ammeter A_1 in the circuit, and connecting the voltmeter across the terminal.

On the graph sheets "I" is the current in amperes: E, is the closed circuit voltage: E_o is the open circuit voltage: D is the density in Faraday units: and "r" is the resistance of the cell.

The value of "r" is determined from the known values of E_1, E_2, and I by use of the formula,

$$r = \frac{E_2 - E_1}{I}$$

The temperature, density, current, open and closed circuit voltage was determined every eight hours for a period of 560 hours. In test # 1, the cell was discharged through a fixed resistance at an average rate of .2097 amperes. The average potential applied being 1.554 volts. The circuit was disturbed but momertarily when the readings were taken.

Curves for each of the cells tested were plotted showing the relation between amperes, volts, temperature and time in hours. Care was used in plotting the curves, they being secured by plotting from point to point and the average value of the ordinates determined by the use of a planimeter.

Calculations and Results.

It will be noticed from a consideration of the data, that the resistance of cell # 1 increased from .1571 to .246 ohms, and that the value was affected slightly by temperature.

Knowing the average voltage and current per cell, the watts output may be calculated from the formula:

$$W = E_1 I$$

The value of "r" is calculated from the known value of E_1, E_2, and I by use of the formula,

$$r = \frac{E_1 - E_2}{I}$$

The temperature, density, current, and closed circuit voltage were determined every eight hours for a period of 360 hours. In test # 1, the cell was discharged through a fixed resistance at an average rate of .2007 amperes. The average potential applied being 1.77 volts. The circuit was disturbed only momentarily when the readings were taken.

Curves for each of the cells tested were plotted showing the relation between amperes, volts, temperature and time in hours. Care was used in plotting the curves, accuracy being assured by plotting every point and the average value of the ordinates determined by the use of a planimeter.

Calculations and Results.

It will be noticed from a consideration of the data, that the resistance of cell # 1 increased from .1571 to .246 ohm, and that the value was affected slightly by temperature.

Knowing the average voltage and current per cell, the watts output may be calculated from the formula:

$$W = E_1 I$$

and knowing the total number of hours the cells were discharged, the total watt-hours per cell may be determined by the use of the formula:

$$W^1 = E \; I \; t$$

in which W^1 equals output in watt-hours, and t is total time in hours.

Both the inner and outer solutions, in this test had a density of 15^0 Baume at 70^0 Fahrenheit.

weight of zinc + Hg before test = 6.05875

weight of zinc + Hg after test = 5.707

weight of zinc consumed = .35175# or 160 grams.

The area of the ampere-hour curve = 29.22 sq. in.

1 sq. in. = 4 ampere-hours giving 116.88 ampere-hours giving an average I of .2097 or ampere-hours output = .2097 x 560 = 116.88.

Theoretical loss = 116.88 x 3600 x .000336 = 141.5 grammes of zinc, in which 3600 is a conversion factor for changing ampere-hours into coulombs, namely amperes per second, and .000336 is the electro-chemical equivalent of zinc.

Therefore 18.5 grammes are consumed by local action and the efficiency is 141.5 ÷ 160 or 88.5 %.

and knowing the total number of hours the cells were discharged, the total watt-hours per cell may be determined by the use of the formula:

$$W^1 = E\ I\ t$$

in which W^1 equals output in watt-hours, and t is total time in hours.

Both the inner and outer solutions, in this test had a density of 15° Baume at 70° Fahrenheit.

weight of zinc-Hg before test = 6.0587[illegible]

weight of zinc-Hg after test = 5.70[illegible]

weight of zinc consumed = .35274 or 160 grams.

The area of the ampere-hour curve = 29.97 sq. in.

1 sq. in. = 4 ampere-hours giving 119.88 ampere-hours giving an average of 1 of .2997 or ampere-hours output = .2997 x 400 = 119.88.

Theoretical loss = 119.88 x 3600 x .000339 = 141.5 grammes of zinc, in which 3600 is a conversion factor for changing ampere-hours into coulombs, namely amperes per second, and .000339 is the electro-chemical equivalent of zinc.

Therefore 18.5 grammes are consumed by local action and the efficiency is 141.5 ÷ 160 or 88.5 %.

Cost of Materials

Cell # 1.

Weight of outer solution = 6.355 lbs.

Weight of cup solution = 3.847 lbs.

Total weight of solution =10.202 lbs.

Since density of acid = 15° Baume = 1.116 sp. gr.

wt. of 1.116 sp. gr. solution per cu. ft. = 69.6022,

per cent of acid in 1.116 sp. gr. solution = 15.904,

therefore weight of actual acid in solution = 10.202 lbs. x .15904 = 1.61 lbs.

As the cells were not completely exhausted, the chemical equivalent of material used would be as follows: H_2SO_4 consumed equals atomic wt. of H_2SO_4 $\div \frac{97.92}{64.82}$ = 1.509.

The actual consumption of 100% acid equals 1.509 x .35175 lbs. zn. = .565 lbs. of acid.

The commercial acid consumed equals .565 $\div$ .96 = .589 lbs. commercial acid consumed. Then at 1.5 cents per pound, the acid used would cost .884 Cents

The K Clo_3 consumed would be determined as follows: since one molecule of K Clo_3 combines with six molecules of H and as,

$3\ zn + 3H_2SO_4 = 3znSO_4 + 6H$

$6H + KClo_3 = KClo_3 = K\ Cl + 3H_2O$

therefore atomic weight of K ClO_3 ÷ atomic wt. of H_2SO_4 will equal amount of K ClO_3 required or, 122.28 ÷ 293.76 = .418 times actual acid used, or .418 x .589 = .246 lbs K ClO_3, and since K ClO_3 costs 9.5 cents per pound, the amount consumed would cost 2.318 cents.

Zinc consumed = .35175 lbs. and costs at 8.5 cents p per pound, 3 cents.

The total cost of the material used in the cell when the average voltage of cell was 1.554 volts, and the average current was .209 amperes for 560hrs. giving 181.2 watt-hours, was as follows: assuming the available chemical efficiency as 80% for the H_2SO_4 and K ClO_3 would be 7.02 cents.

The cost per K.W. hr. output would be 38.7 cts. The foregoing cost shows the possible minimum of commercial cost per K.W.hr. based upon a chemical efficiency of 80% which seems to have been obtained on complete discharge tests.

therefore atomic weight of K ClO_3 - atomic wt. of H_2SO_4 will equal amount of K ClO_3 required or,122.56 - 293.24 = .418 times actual acid used, or .418 x .583 = .244 lbs K ClO_3,and since K ClO_3 costs 9.5 cents per pound,the amount consumed would cost 2.318 cents.

Zinc consumed = .35175 lbs.and costs at 8.5 cents a per pound, 3 cents.

The total cost of the material used in the cell when the average voltage of cell was 1.554 volts, and the average current was .209 amperes for 560hrs. giving 181.2 watt-hours,was as follows: assuming the available chemical efficiency as 80% for the H_2SO_4 and K ClO_3 would be 7.02 cents.

The cost per K.W. hr. output would be 38.7 cts.

The foregoing cost shows the possible minimum of commercial cost per K.W.hr. based upon a chemical efficiency of 80% which seems to have been obtained on complete discharge tests.

CELL NO. I.

Time	E 1	E 2	I	Density	r.	Hrs.
2 AM		.16	0	15		
2 PM		1.832		16.0		
10	1.723	1.766	.21	16.2	.1571	8
6 AM	1.70	1.734	.22	16.4	.1545	16
2 PM	1.73	1.765	.225	16.5	.1555	24
10	1.74	1.776	.21	16.45	.171	32
6 AM	1.66	1.706	.215	16.8	.168	40
2	1.63	1.666	.21	16.9	.171	48
10	1.594	1.63	.199	17.	.181	56
6 AM	1.587	1.620	.20	17.1	.180	64
2 PM	1.58	1.618	.205	17.4	.186	72
	6 oz. H_2O added					
10	1.594	1.63	.21	15.9	.171	80
6 AM	1.574	1.61	.203	16.5	.177	88
2 PM	1.572	1.61	.203	17.5	.187	96
10	1.656	1.695	.215	17.4	.181	104
6 AM	1.547	1.586	.215	17.4	.183	112
2 PM	1.555	1.596	.2151	17.5	.199	120
10	1.536	1.576	.205	18.	.197	128
6 AM	1.600	1.639	.209	17.8	.186	136
	6 oz. H_2O added					

C E L L No. I

Time	E 1	E 2	I	Density	r.	Hrs.
2 AM		1.16	0	15		
2 PM		1.932		15.0		
10	1.723	1.756	.21	16.2	.1571	8
6 AM	1.70	1.754	.22	16.4	.1545	16
2 PM	1.73	1.765	.225	16.5	.1555	24
10	1.74	1.776	.21	16.45	.171	32
6 AM	1.66	1.706	.215	16.8	.168	40
2	1.65	1.666	.21	15.9	.171	48
10	1.694	1.68	.19	17.	.187	56
6 AM	1.597	1.520	.20	17.1	.180	64
2 PM	1.55	1.618	.205	17.4	[illegible]	72
	6 oz. MgO added					
10	1.564	1.65	.21	17.2	.171	80
6 AM	1.574	1.51	.205	16.6	.177	88
2 PM	1.572	1.51	.205	17.6	.177	96
10	1.556	1.695	.215	17.4	.183	104
6 AM	1.547	1.586	.215	17.4	.183	112
2 PM	1.565	1.556	.2151	17.5	.194	120
10	1.586	1.576	.203	18.	.27	128
6 AM	1.601	1.585	.204	17.	.190	136
	6 ... MgO added					

C E L L NO. I.

Time	E 1	E 2	I	Density	r	Hrs.
2 PM	1.62	1.658	.22	15.	.175	144
10	1.598	1.646	.22	16.	.177	152
6 AM	1.566	1.606	.21	17.7	.190	160
2 PM	1.57	1.61	.212	17.7	.188	168
10	1.576	1.616	.212	17.7	.194	176
6 AM	1.576	1.617	.22	17.5	.186	184
2 PM	1.581	1.618	.219	17.	.169	192
10	1.584	1.626	.216	17.5	.194	200
6 AM	1.605	1.646	.219	18.	.187	208
	6 oz. H_2O added					
2 PM	1.588	1.628	.218	16.3	.185	216
10	1.585	1.626	.218	16.3	.186	224
6 AM	1.585	1.626	.212	17.2	.196	232
2 PM	1.582	1.623	.213	17.2	.195	240
10	1.569	1.61	.208	17.5	.197	248
6 AM	1.51	1.551	.208	18.	.197	256
2 PM	1.534	1.575	.21	19.	.195	264
10	1.535	1.576	.211	19.1	.194	272
6 AM	1.524	1.565	.21	19.5	.197	280

C E L L NO. I.

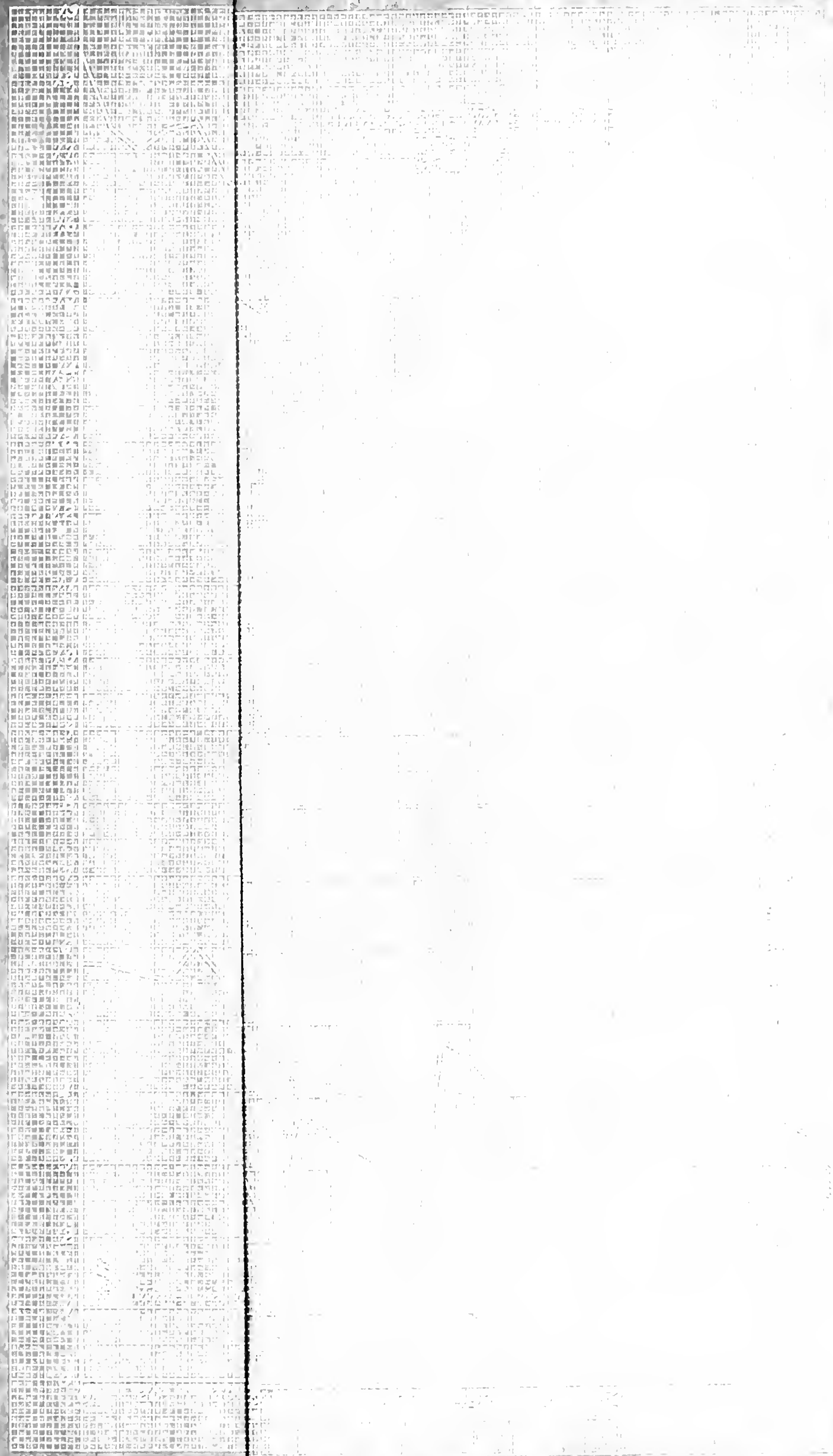
Time	E 1	E 2	I	Density	r	Hrs.
2 PM	1.541	1.583	.213	20.	.209	288
10	1.54	1.582	.213	20.	.208	296
6 AM	1.524	1.566	.2	20.1	.21	304
2 PM	1.534	1.576	.2	20.2	.21	312
10	1.525	1.57	.21	20.8	.208	320
6 AM	1.518	1.56	.2	20.9	.21	328
	6 oz. H_2O added					
2 PM	1.557	1.570	.208		.207	336
10	1.52	1.563	.202	21.7	.213	344
6 AM	1.526	1.569	.203	21.	.216	352
2 PM	1.534	1.577	.208	20.7	.207	360
10	1.527	1.57	.208	21.	.207	368
6 AM	1.517	1.569	.212	21.5	.203	376
2 PM	1.516	1.558	.208	22.	.202	384
10	1.518	1.56	.203	22.1	.207	392
6 AM	1.503	1.546	.209	22.5	.206	400
2 PM	1.502	1.546	.209	22.5	.211	408
10	1.514	1.558	.21	22.8	.209	416
6 AM	1.486	1.53	.208	22.9	.216	424
2 PM	1.53	1.566	.208	23.	.208	432

C E L L NO. 1.

Time	E 1	E 2	I	Density	r	Hrs.
2 PM	1.541	1.583	.213	20.	.208	288
10	1.54	1.582	.213	20.	.208	296
6 AM	1.534	1.566	.2	20.1	.21	304
2 PM	1.534	1.576	.2	20.2	.21	312
10	1.523	1.57	.21	20.8	.208	320
6 AM	1.518	1.56	.2	20.9	.21	328
6 oz. H_2O added						
2 PM	1.537	1.570	.206		.207	336
10	1.52	1.563	.206	21.7	.213	344
6 AM	1.526	1.569	.203	21.	.216	352
2 PM	1.534	1.577	.208	20.7	.207	360
10	1.527	1.57	.208	21.	.207	368
6 AM	1.517	1.569	.213	21.5	.203	376
2 PM	1.516	1.558	.208	22.	.207	384
10	1.518	1.56	.208	22.1	.207	392
6 AM	1.503	1.546	.209	22.5	.205	400
2 PM	1.502	1.546	.209	22.5	.211	408
10	1.514	1.558	.21	22.8	.209	416
6 AM	1.486	1.53	.204	22.[illegible]	.216	424
2 PM	1.53	1.556	.208	22.	.208	432

C E L L NO. I.

Time	E 1	E 2	I	Density	r	Hrs
10 PM	1.52	1.566	.209	23.	.206	440
6 AM	1.524	1.558	.211	23.5	.208	448
2 PM	1.511	1.556	.21	24.	.214	456
10 PM	1.505	1.545	.21	23.9	.214	464
6 AM	1.515	1.560	.209	24.1	.215	472
2 PM	1.486	1.532	.213	24.	.216	480
	6 oz. H_2O added					
10	1.476	1.523	.21	22.5	.222	488
6 AM	1.52	1.566	.212	22.8	.217	496
2 PM	1.52	1.566	.21	23.1	.219	504
10	1.524	1.57	.21	23.2	.219	512
6 AM	1.490	1.536	.211	24.	.218	520
2 PM	1.50	1.546	.218	24.2	.224	528
10 PM	1.476	1.52	.2	24.5	.21	536
6 AM	1.51	1.557	.205	24.1	.229	544
2 PM	1.52	1.57	.203	24.8	.246	552
10 P.M.	1.47	1.52	.205	25.	.24	560



PART II.

Test # 2.

DISCHARGING AT AN INTERMITTANT RATE.

Test # 2.

Cell # 2.

In this test the cell was prepared the same as in Test#1 using a solution having the same density. The cell was automatically discharged for a period of 10.5 seconds once during each two minutes through a resistance giving an average value of current of 2.88 amperes.

The quantities on the data sheets for this test have the same meaning as in Test # 1.

Calculations and Results.

Weight of zn+ Hg before test = 6.0586 lbs.

Weight of Zn + Hg after test = 5.642 lbs.

Weight of Zn consumed = .4166 lbs.= 188 gms.

In 560 hours there were 560 x 30 or 16800 contacts of 10.5 seconds each at 2.88 amperes or equivalent to 49x 2.88 = 141.2 x 3600 x .000336 = 171.1 gms.

Curves were plotted showing the variation of amperes volts and temperature of the cell with time in hours. The curves being determined by plotting from point to point. The areas of the ampere-time curve, and volt-time curve were determined accurately by the use of a planimeter, and the average value of the current and voltage were determinedtherefrom.

The zinc consumed by local action in this cell

Test # 2.

Cell # 2.

In this test the cell was prepared the same as in Test#1 using a solution having the same density. The cell was automatically discharged for a period of 10.5 seconds once during each two minutes through a resistance giving an average value of current of 2.89 amperes.

The quantities on the data sheets for this test have the same meaning as in Test # 1.

Calculations and Results.

Weight of Zn + Hg before test = 6.0586 lbs.

Weight of Zn + Hg after test = 5.642 lbs.

Weight of Zn consumed = .4166 lbs. = 189 gms.

In 560 hours there were 560 x 30 or 16800 contacts of 10.5 seconds each at 2.89 amperes or equivalent to 49x 2.89 = 141.2 x 3600 x .[illegible] = 171.1 gms.

Curves were plotted showing the variation of ampere volts and temperature of the cell with time in hours. The curves being determined by plotting from point to point. The areas of the ampere--time curve, and volt-time curve were determined accurately by the use of a planimeter, and the average value of the current and voltage were determined therefrom.

The zinc consumed by local action in this cell

was 16.9 gms.,therefore the efficiency was 91.25%

Cost of Materials.

Weight of outer solution = 7.337 lbs.

Weight of inner solution = 3.106 lbs.

Total weight of solution =10.443 lbs.

Since the density of acid = 15°Baum,or 1.116 lbs sp.gr.,a cu. ft. of this liquid weighs 69.6032 lbs, and contains 15.904% acid,the weight of acid in liquid is 1.67 lbs.

H_2SO_4 consumed = 1.509 x .4166 lbs. = .629 lbs. 100% acid or .655 lbs. commercial acid,which would cost .987 cents. The $K\,Clo_3$ consumed equals.418 x .655 = . 272 lbs.,or zinc consumed would cost 3.549 cents.

The total cost of materials consumed allowing 80% chemical efficiency for H_2SO_4 and $K\,Clo_3$,in producing 186 watts is 7.689 cents or 43.1 cents per K.W. hour.

C E L L NO. II.

Time	E 1	E 2	I	Density	r	Hrs.
2 AM		.16		15.		
12:30 PM		1.821		16.5		
10	1.46	1.761	2.81	17.	.106	8
6 AM	1.44	1.76	2.85	17.	.109	16
2 PM	1.506	1.81	2.81	17.	.109	24
10 PM	1.46	1.76	2.9	17.	.105	32
6 AM	1.426	1.761	3.11	17.	.107	40
	14.5 oz. H_2O added					
2 PM	1.377	1.717	3.11	15.	.1094	48
10	1.387	1.717	3.1	16.1	.105	56
6 AM	1.38	1.711	3.06	16.2	.107	64
2 PM	1.356	1.678	3.05	16.8	.1058	72
10	1.36	1.666	3.06	16.5	.100	80
6 AM	1.33	1.64	3.09	16.8	.100	88
2 PM	1.338	1.638	2.99	17.	.1008	96
10	1.336	1.64	2.995	17.5	.103	104
6 AM	1.35	1.674	3.01	17.5	.1075	112
2 PM	1.34	1.65	3.02	17.4	.102	120

C E L L NO. II.

Time	E 1	E 2	I	Density	r	Hrs.
10 PM	1.34	1.65	3.02	18.5	.102	128
6 AM	1.336	1.646	2.93	18.2	.102	136
	3 oz. H_2O added					
2 PM	1.326	1.66	2.89	17.5	.1176	144
10	1.317	1.636	2.89	16.5	.109	152
6 AM	1.318	1.618	2.98	17.2	.1006	160
2 PM	1.33	1.636	2.99	17.5	.104	168
10	1.336	1.606	2.86	17.5	.107	176
6 AM	1.33	1.616	2.83	18.	.1008	184
2 PM	1.34	1.62	2.875	17.8	.1004	192
10	1.336	1.616	2.83	18.1	.099	200
6 AM	1.332	1.62	2.87	18.6	.1001	208
	6 oz. H_2O added					
2 PM	1.336	1.617	2.9	18.1	.0973	216
10	1.358	1.638	2.81	18.6	.0998	224
6 AM	1.346	1.617	2.82	18.8	.0995	232
2 PM	1.336	1.628	2.89	19.3	.0975	240

CELL NO. II.

Time	E 1	E 2	I	Density	r	Hrs.
10 PM	1.336	1.616	2.91	20.	.0963	248
6 AM	1.296	1.606	2.86	20.	.1085	256
2 PM	1.306	1.611	3.01	21.	.1012	264
10	1.296	1.586	2.91	21.3	.0998	272
6 AM	1.296	1.616	2.81	21.8	.114	280
2 PM	1.316	1.621	2.96	21.9	.1028	288
10 PM	1.311	1.616	2.89	22.	.1055	296
6 AM	1.316	1.62	2.89	22.8	.105	304
2 PM	1.316	1.616	2.94	22.8	.1021	312
10 PM	1.296	1.586	2.89	23.	.1008	320
6 AM	1.3	1.596	2.89	23.5	.1002	328
2 PM	1.296	1.596	2.86	23.	.105	336
	6 oz. H_2O added					
10	1.3	1.39	2.87	23.	.101	344
6 AM	1.268	1.55	2.8	23.5	.101	352
2 PM	1.30	1.596	2.84	24.	.104	360
10	1.32	1.596	2.84	24.	.097	368
6 AM	1.3	1.586	2.83	25.	.1011	376

C E L L NO. II.

Time	E 1	E 2	I	Density	r	Atm.
10 PM	1.336	1.616	2.91	20.	.0963	248
6 AM	1.296	1.606	2.86	20.	.1087	256
2 PM	1.306	1.611	[illegible]	21.	[illegible]	264
10	1.295	1.586	2.91	21.3	.0996	271
6 AM	1.296	1.616	2.91	21.8	.114	280
2 PM	1.316	1.621	2.96	21.9	.1024	288
10 PM	1.311	1.516	2.89	22.	.1056	296
6 AM	1.316	1.62	2.90	22.8	.105	304
2 PM	1.316	1.616	2.94	22.3	.1021	312
10 PM	1.296	1.586	2.9	23.	.1004	320
6 AM	1.3	1.596	2.99	23.5	.1002	328
2 PM	1.296	1.596	2.96	23.	.105	336
	6 cc. H_2O added					
10	1.3	1.59	2.87	23.	.101	344
6 AM	1.266	1.55	[illegible]	23.5	.101	352
2 PM	1.30	1.550	2.94	24.	.104	[illegible]
10	1.32	1.595	2.94	24.	.097	[illegible]
6 AM	1.3	1.566	[illegible]	25.	[illegible]	[illegible]

C E L L NO. II.

Time	E 1	E 2	I	Density	r	Hrs.
2 PM	1.28	1.576	2.81	25.	.102	384
10	1.26	1.578	2.56	25.	.118	392
6 AM	1.242	1.576	2.76	25.	.121	400
2 PM	1.262	1.576	2.73	25.1	.1151	408
10	1.25	1.564	2.83	25.5	.111	416
6 AM	1.22	1.558	2.93	26.	.1161	424
2 PM	1.22	1.556	2.89	25.5	.113	432
10	1.24	1.559	2.89	26.	.1102	440
6 AM	1.23	1.566	3.01	26.3	.113	448
2 PM	1.24	1.566	2.74	26.3	.119	456
10 PM	1.25	1.576	2.81	26.4	.116	464
6 AM	1.24	1.566	2.86	27.5	.114	472
2 PM	1.26	1.571	2.8	26.5	.113	480
	6 oz. H_2O added					
10 PM	1.24	1.566	2.7	25.5	.1208	488
6 AM	1.23	1.576	2.71	26.5	.1276	496
2 PM	1.23	1.576	2.81	26.2	.1241	504

CELL NO. II.

Time	E 1	E 2	I	Density	r	Hrs.
10 PM	1.21	1.556	2.80	26.5	.1278	512
6 AM	1.21	1.546	2.73	27.1	.123	520
2 PM	1.30	1.637	2.80	27.1	.121	528
10 PM	1.21	1.556	2.71	27.1	.1277	536
6 AM	1.24	1.576	2.7	27.4	.1212	544
2 PM	1.2	1.556	2.76	27.4	.128	552
10	1.2	1.536	2.71	28.1	.124	560

C E L L NO. II.

Time	E 1	E 2	I	Tensi-ty	r	Tr..
10 PM	1.21	1.565	2.80	25.5	.1576	[illegible]
6 AM	1.21	1.546	2.73	27.1	.125	[illegible]
2 PM	1.30	1.657	2.80	27.1	.121	[illegible]
10 PM	1.21	1.556	2.71	27.1	.1277	[illegible]
6 AM	1.24	1.576	2.7	27.4	.1218	[illegible]
2 PM	1.2	1.555	2.75	27.4	.12	[illegible]
10	1.2	1.536	2.71	26.1	.124	[illegible]

[illegible]

PART III.

Test # 3.

DISCHARGING CELL AT AN INTERMITTANT RATE.

Test # 3.

Cell # 3.

In this test the cell was prepared and operated under practically the same conditions as cell # 2, with the exception that the value of the current was a little lower.

Curves were plotted as in previous tests, showing the variation in the value of amperes, volts and temperature with respect to time in hours. The same care was taken in obtaining the average values, as was previously exercised.

Calculations and Results.

Weight of zinc + mercury before test	6.0625 lbs.
Weight of zinc + mercury after test	5.663 lbs.

Weight of zinc consumed = .3995 lbs = 181.5 gms.

The number of hours in service was 560, the number of contacts was 16800 and the amp-hrs = 49 x 136.5.

The theoretical value of the loss of zinc = 136.5 x 3600 x .000336 = 165.1 gms. The zinc consumed by local action was 16.4 gms., giving an efficiency of 91.25 %.

Cost of Materials.

Weight of outer solution	6.739 lbs.
Weight of inner solution	3.536 lbs.
Total weight of solution	10.275 lbs.

Amount of acid in 10.275 lbs. of solution = 1.635 lbs. H_2SO_4 consumed in the cell = 1.509x.3995= .602 lbs. of 100 % acid or .627 lbs. of commercial acid, and would

Test # 3.

Cell # 3.

In this test the cell was prepared and operated under practically the same conditions as cell # 2,with the exception that the value of the current was a little lower.

Curves were plotted as in previous tests,showing the variation in the value of amperes,voltage,and temperature with respect to time in hours.The same care was in obtaining the average values,as was previously exercised.

Calculations and Results.

Weight of zinc mercury before test	4.0093 lbs.
Weight of zinc mercury after test	[illegible] lbs.

Weight of zinc consumed = .2925 lbs = 131.5 gms.

The number of hours in service was [illegible],the number of contacts was 16900 and the amp-hrs = 49 x 139.5.

The theoretical value of the loss of zinc = 136.5 x 3600 x .000336 =165.1 gms. The zinc consumed by local action was 16.4 gms.,giving an efficiency of 91.58 %.

Cost of Materials.

Weight of outer solution	9.72[illegible] lbs.
Weight of inner solution	3.526 lbs.
Total weight of solution	13.[illegible] lbs.

Amount of acid in 1.375 lbs. of solution = [illegible] lbs.

H_2SO_4 consumed in the cell = 1.50 x .5993 = .899 lbs. of 100 % acid or .927 lbs. of commercial acid, and would

cost .94 cents. $KClO_3$ consumed =.418 x .627 = .262 lbs. and costs 2.57 cents and zn consumed = 3.381cents.

The total cost of materials consumed allowing 80% for chemicals used is 7.76 cts.for 178.2 watt-hrs. or 43.4 cts. per K.W.Hr.

C E L L NO. III.

Time	E 1	E 2	I	Density	r	Hrs.
2 AM		.16		15.		
12:30 PM		1.82		16.5		
10 PM	1.456	1.746	2.51	16.	.111	8
6 AM	1.456	1.746	2.51	16.2	.111	16
2 PM	1.481	1.78	2.61	16.5	.114	24
10	1.481	1.776	2.6	16.5	.113	32
	14.4 oz. H_2O added					
6 AM	1.48	1.775	2.77	15.	.108	40
2 PM	1.43	1.741	2.83	16.1	.107	48
10	1.435	1.735	2.85	16.5	.105	56
6 AM	1.431	1.714	2.72	16.55	.104	64
2 PM	1.35	1.676	3.	16.8	.1068	72
10	1.355	1.68	3.1	16.7	.1045	80
6 AM	1.338	1.663	2.9	17.	.105	88
2 PM	1.378	1.664	2.69	17.5	.106	96
10	1.32	1.66	3.3	17.5	.103	104
6 AM	1.325	1.674	3.3	17.5	.104	112
2 PM	1.31	1.65	3.33	17.4	.103	120

C E L L NO. III.

Time	E 1	E 2	I	Density	r	Hrs.
10 PM	1.31	1.65	3.33	18.5	.103	128
	3 oz. H20 added					
6 AM	1.33	1.66	3.1	17.5	.1062	136
2 PM	1.46	1.76	2.83	16.	.1058	144
10	1.34	1.65	2.9	16.6	.107	152
6 AM	1.361	1.651	2.83	17.	.1050	160
2 PM	1.3	1.594	2.89		.1019	168
10	1.32	1.636	2.93		.1072	176
6 AM	1.34	1.631	2.91		.1	184
2 PM	1.3	1.611	2.72		.1182	192
10	1.33	1.646	2.52		.1162	200
6 AM	1.36	1.66	2.71		.1108	208
	6 oz. H_2O added					
2 PM	1.32	1.616	2.74		.1081	216
10	1.345	1.656	2.66	19.	.117	224
6 AM	1.33	1.634	2.66	19.	.1142	232
2 PM	1.315	1.646	2.82	19.5	.1174	240

C E L L NO. III.

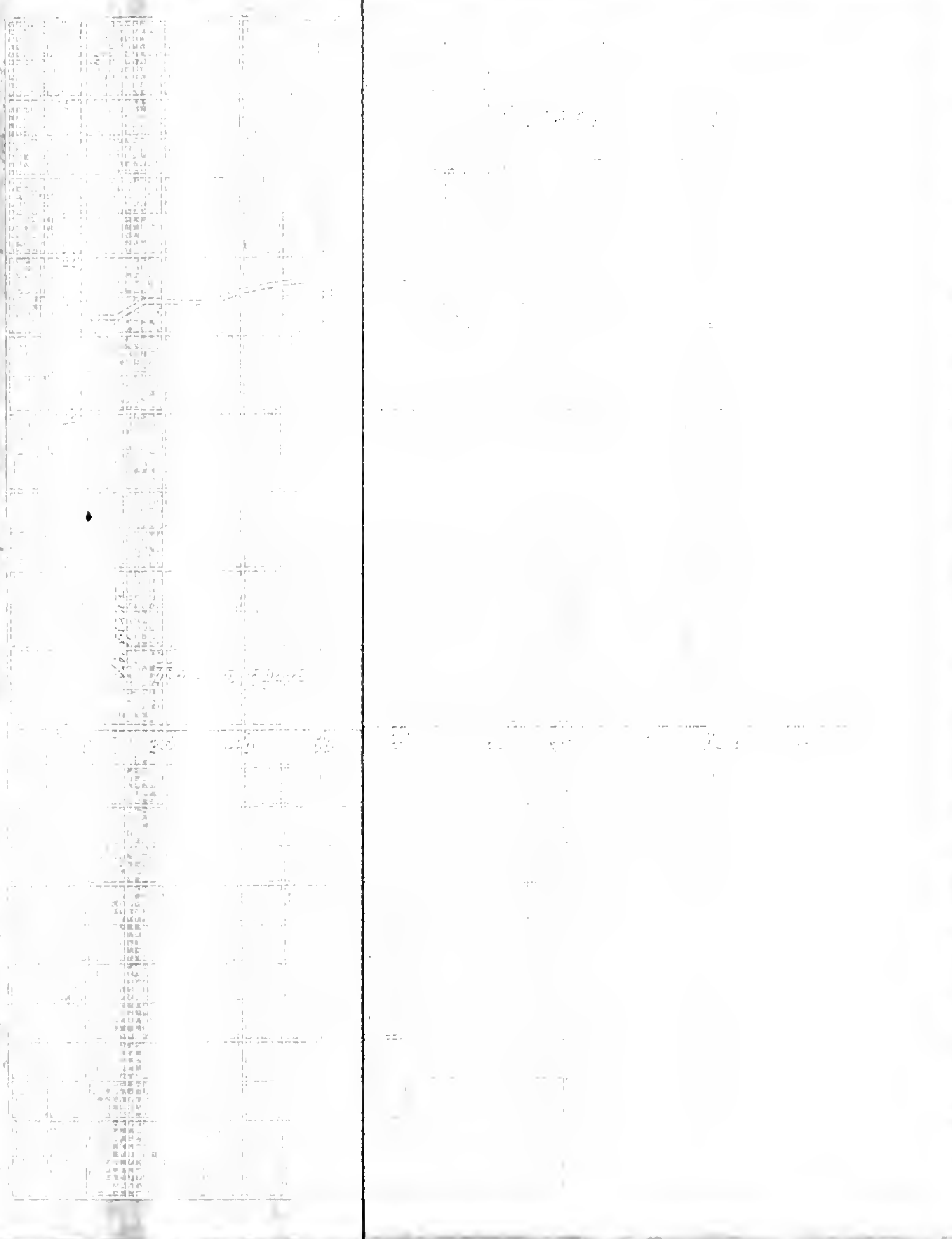
Time	E 1	E 2	I	Density	r	Hrs.
10 PM	1.318	1.614	2.81	19.9	.1055	248
6 AM	1.32	1.626	2.81	20.0	.1088	256
2 PM	1.32	1.636	2.73	21.	.1158	264
10 PM	1.31	1.626	2.66	21.	.1188	272
6 AM	1.31	1.616	2.68	21.4	.1143	280
2 PM	1.32	1.646	2.73	21.8	.1197	288
10	1.32	1.616	2.91	22.	.1018	296
6 AM	1.21	1.506	2.66	22.5	.1112	304
2 PM	1.26	1.586	2.74	22.7	.119	312
10	1.265	1.60	2.86	23.	.117	320
6 AM	1.26	1.591	2.79	23.2	.1185	328
2 PM	1.3	1.616	2.89		.1094	336
	6 oz. H_2O added					
10	1.3	1.606	2.99	23.2	.1023	344
6 AM	1.3	1.614	2.81	23.2	.1118	352
2 PM	1.3	1.596	2.75	23.2	.1078	360
10	1.255	1.596	2.86	23.5	.1192	368

C E L L NO. III.

Time	E 1	E 2	I	Density	r	Hrs.
6 AM	1.24	1.58	2.86	23.6	.1188	376
2 PM	1.24	1.56	2.77	24.5	.1175	384
10	1.242	1.576	2.83	24.2	.118	392
6 AM	1.236	1.57	2.81	25.	.119	400
2 PM	1.236	1.57	2.81	25.1	.1188	408
10	1.24	1.576	2.82	25.8	.119	416
6 AM	1.25	1.566	2.65	25.9	.1192	424
2 PM	1.235	1.57	2.83	26.	.1182	432
10	1.23	1.56	2.82	26.3	.119	440
6 AM	1.22	1.571	2.72	26.6	.129	448
2 PM	1.25	1.574	2.51	26.8	.129	456
10	1.24	1.574	2.66	26.6	.1255	464
6 AM	1.24	1.574	2.69	27.3	.129	472
2 PM	1.22	1.576	2.76	27.5	.129	480
	6 oz. H_2O added.					
10	1.222	1.576	2.71	26.2	.1307	488
6 AM	1.23	1.566	2.56	26.8	.1312	496

C E L L NO. III.

Time	E 1	E 2	I	Density	r	Hrs.
2 PM	1.22	1.556	2.54	26.8	.1345	504
10	1.26	1.556	2.53	27.5	.133	512
6 AM	1.21	1.556	2.51	28.	.138	520
2 PM	1.28	1.646	2.73	28.4	.1376	528
10	1.24	1.606	2.51	27.4	.138	536
6 AM	1.23	1.584	2.56	28.	.1382	544
2 PM	1.26	1.57	2.41	28.	.1289	552
10	1.24	1.534	2.11	28.8	.139	560



PART IV.

TEST # 4.

TEST OF A COPPER SULPHATE CELL.

Part IV.

Test # 4.

In this test a copper sulphate cell was used. The cell was prepared by placing the copper electrode in the bottom of the jar and placing 1.5 lbs. of pulverized copper sulphate or "blue stone" in cell and then filling jar to within.5 inches of the top.The cell was then short circuited for 12 hours to secure a normal condiiton of operation. The weight of each part entering into the construction of the cell was carefully ascertained.

The current,voltage,and temperature were observed at the same time as these quantities were observed of the other cells.

Curves were plotted showing the value of these quantities with respect to time. The areas of the curves were determined with a planimeter and the average values determined therefrom.

Calculations and Results.

Weight of zn consumed was 1.472 lbs or 668 gms.The theoretical value of the zn consumed is 89.4 amp-hrs x 3600 x .000336 =108 gms.

The zn evidently consumed by local action was 560 gms.,giving an efficiency of 16.2%.

Cost of Materials.

Cost of zn at 7cts.per lb was 12.9 cts. and cost

Part IV.

Test # 4.

In this test a copper sulphate cell was used. The cell was prepared by placing the copper electrode in the bottom of the jar and placing 1.5 lbs. of crystallized copper sulphate or "blue stone" in cell and then filling jar to within 5 inches of the top. The cell was then short circuited for 12 hours to secure a normal condition of operation. The weight of each part entering into the construction of the cell was carefully ascertained.

The current, voltage, and temperature were observed at the same time as these quantities were observed of the other cells.

Curves were plotted showing the value of these quantities with respect to time. The areas of the curves were determined with a planimeter and the average values determined therefrom.

Calculations and Results.

Weight of zn consumed was 1.[illegible] lbs or [illegible] gms. The theoretical value of the zn consumed is [illegible].4 amp-hrs x [illegible] x .000338 = 108 gms.

Zn actually consumed by local action was 5[illegible] gms., giving an efficiency of 16.[illegible]%.

Cost of Materials.

Cost of zn at 7cts.per lb was [illegible] cts. and cost

of copper sulphate at 7 cts.per lb. was 10.5 cts, giving a total cost of 23.4 cts. for 25.5 watt-hrs. or $9.17 per K.W.Hr.

C E L L NO. IV.

Time	E 1	E 2	I	Density	r	Hrs.
2PM	.35	1.1	.285		2.57	8
10	.34	1.1	.266		2.75	16
6 AM	.34	1.1	.269		2.75	24
2 PM	.32	1.1	.269		2.78	32
10	.19	.99	.246		3.26	40
6 AM	.314	1.1	.23		3.	48
2 PM	.318	1.1	.227		3.49	56
10	.321	1.1	.233		3.35	64
6 AM	.329	1.15	.22		3.49	72
2 PM	.342	1.08	.235		3.26	80
10	.33	1.08	.222		2.96	88
6 AM	.33	1.06	.244		2.99	96
2 PM	.395	1.08	.26		2.64	104
10	.31	1.03	.25		2.88	112
6 AM	.31	.99	.23		3.05	120
2 PM	.31	1.01	.25		2.84	128

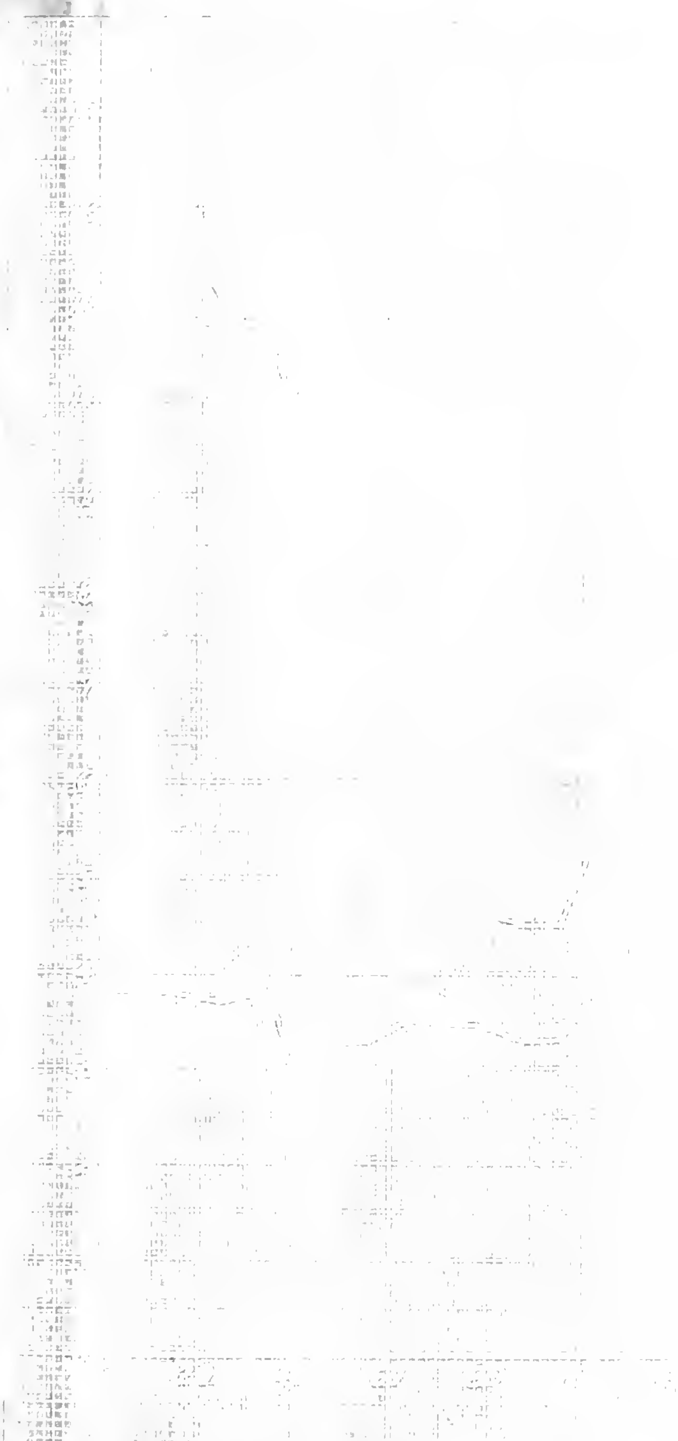
C E L L NO. IV.

Time	E 1	E 2	I	Density	r	Hrs.
10 PM	.28	1.	.252		2.86	136
6 AM	.30	.96	.225		3.07	144
2 PM	.25	.92	.215		3.12	152
10	.25	.92	.215		3.12	160
6 AM	.24	.91	.214		3.15	168
2 PM	.243	.913	.215		3.02	176
10	.24	.90	.215		3.12	184
6 AM	.22	.89	.22		2.96	192
2 PM	.268	.91	.23		2.82	200
10	.22	.89	.22		2.98	208
6 AM	.22	.88	.22		3.00	216
2 PM	.315	.96	.233		2.92	224
10	.32	.97	.22		2.95	232
6 AM	.31	.965	.23		2.90	240
2 PM	.31	.964	.235		2.90	248
10	.315	.97	.23		2.84	256
6 AM	.29	.95	.228		2.9	264

C E L L NO. IV.

Time	E 1	E 2	I	Density	r	Hrs.
2 PM	.27	.93	.22		3.	272
10	.28	.94	.22		3.02	280
6 AM	.275	.95	.22		3.06	288
2 PM	.30	.975	.24		2.81	296
10	.29	.96	.22		3.06	304
6 AM	.28	.93	.215		3.03	312
2 PM	.24	.89	.215		3.03	320
10	.21	.88	.22		3.04	328
6 AM	.198	.83	.221		3.	336
2 PM	.26	.83	.2		2.95	344
10	.16	.78	.19		3.26	352
6 AM	.11	.52	.125		3.35	360

[illegible]



PART IV.

SUMMATION AND DISCUSSION OF RESULTS.

Summation and Discussion of Results.

The highest voltage obtained in this series of tests was 1.832 volts. A greater voltage would evidently have beensecured if the temperature had been a little higher.

From a consideration of the cost of materials it will be noted that cell # 2 gave the greatest watt-hour output in the given time. Cell # 1 gave a watt-hr. output 181.2 watt-hrs. at a cost of 39.75 cts.per K.W. Hr. for energy: cell # 2 gave 186 watt-hrs. at a cost of 43.1 cts. per K.W.Hr. for energy: cell #3 gave 178.2 watt-hrs. at a cost Of 43.4 cts per K.W.Hr and the copper sulphate cell gave 25.5 watt-hrs. at acost of $9.17 per K.W.Hr.

Referring to the volt-time curve it will be noted that cell # 1 maintained an average current of .2097 amperes for 560 hours,with a voltage variation of 17.2 %. The value of the current was maintained with a variation of only 11.1 % with a temperature variation of 8 deg. Centigrade.

Cell # 2 maintained an average current of 2.88 amperes for 560 hours with avoltage variation,figuring from the time the cell action became stable, of 16.08 % and a current variation of 17.2 % with

Summation and Discussion of Results.

The highest voltage obtained in this series of tests was 1.832 volts. A greater voltage would evidently have been secured if the temperature had been a little higher.

From a consideration of the cost of materials it will be noted that cell # 2 gave the greatest watt-hour output in the given time. Cell # 1 gave a watt-hr. output 181.[illegible] watt-hrs. at a cost of [illegible] cts. per K.W. hr. For energy: cell # 2 gave 18[illegible] watt-hrs. at a cost of [illegible]3.1 cts. per K.W.hr. For energy: cell #3 gave 17[illegible] watt-hrs. at a cost of 15.4 cts per K.W.Hr and the copper sulphate cell gave 25.[illegible] watt-hrs. at a cost of $[illegible].17 per K.W.hr.

Referring to the volt-time curve it will be noted that cell # 1 maintained an average current of .209[illegible] amperes for [illegible]60 hours, with a voltage variation of 17.2 %. The value of the current was maintained with a variation of only 11.1 % with a temperature variation of 8 deg. Centigrade.

Cell # 2 maintained an average current of [illegible] amperes for [illegible]60 hours with a voltage variation, figuring from the time the cell action became stable, of 12.8 % and a current variation of 17.[illegible] % with

a temperature variation of 8 deg.C.

Cell #3 maintained an average current of 2.783 amperes and apotential of 1.305 volts, for aperiodof 560 hours, with avoltage variation of 17.81 % and a current variation of 15.8 % , with a temperature variation of 8 deg.C. This was obtained after the action of the cell had become normal and the resistance properly adjusted.

Cell # 4 did not give a very steady value of voltage or current and was greatly affected by the temperature, while the other three cells were not so greatly affected by changes in temperature. This is readily explained by the fact that the resistance of the potassium chlorate cells varied from a minimum of .106 ohms to a maximum of .246 ohms, while the resistance of the copper sulphate cell varied from 2.57 to 3.35 ohms.

It is evident from A consideration of the cost of materials and watt-output that it costs slightly less to operate the cell at a low rate of discharge than at a high rate of discharge.

From a consideration of the above results it is obvious, that as cell # 2 gave an average discharge of 3.8 watts per second, that it would require 53 copper cells to do the work of one $KClO_3$ cell.

a temperature variation of [illegible] deg.C.

Cell #3 maintained an average current of 2.74[illegible] amperes and a potential of 1.1[illegible] volts, for a period of 560 hours, with a voltage variation of 17.[illegible] % and a current variation of 15.[illegible] %, with a temperature variation of [illegible] deg.C. This was obtained after an action of the cell had become normal and the resistance properly adjusted.

Cell # 4 did not give a very steady value of voltage or current and was greatly affected by the temperature, while the other three cells were not so greatly affected by changes in temperature. This is readily explained by the fact that the resistance of the potassium chlorate cells varied from a minimum of .10[illegible] ohms to a maximum of .94[illegible] ohms, while the resistance of the copper sulphate cell varied from 2.57 to 2.5[illegible] ohms.

It is evident from a consideration of the cost of materials and watt-output that it costs slightly less to operate the cell at a low rate of discharge than at a high rate of discharge.

From a consideration of the above results it is obvious, that as cell # [illegible] gave an average [illegible] of 3.[illegible] watts per second, that it would require [illegible] copper cells to do the work of one such cell.

From a final survey of the possibities of this cell, it appears that there is an extensive field in which the $KClO_3$ cell might replace those at present in use, with an enormous saving in cost.

From a final survey of the possibilities of this cell, it appears that there is an extensive field in which the Kolog cell might replace those at present in use, with an enormous saving in cost.